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Management, mechanization and automation of work in the construction of high-rise buildings

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Abstract. The construction of high-rise buildings consists of the implementation of known technological processes for the installation of building structures: foundations, walls, columns, etc. However, the features of these structures and the high-altitude factor on which the work is done predetermine a number of differences in the technology of production of works, which are manifested in the appearance of new or other accentuation of mechanization means, types of work, technological documentation. The most obvious differences of high-rise construction from the positions of the used machines, mechanisms and devices appear in the means for transporting goods and ensuring the safety of work at altitude. On the basis of the analysis of scientific and practical works in the field of design and construction of high-rise objects, the features of the organization and technology of production at these facilities have been determined. The main design solutions of high-rise facilities that affect the technological features of high-rise buildings are revealed. Features of managing the construction of unique high-rise objects are given. The general technological sequence of the investment and construction process for the construction of high-rise buildings has been determined. Specific features of mechanization and production technology for the construction of high-rise buildings in relation to certain types of construction and erection works are worked out (excavation, production of works of the zero cycle, concreting of the foundation slab, installation and finishing works at height, construction of the above-ground part and others).

1 Introduction

According to the famous American architect Frank Lloyd Wright, the progenitor of modern skyscrapers was Michelangelo di Buonarroti, "planted the Pantheon at the Parthenon" [1], creating the St. Peter's Cathedral.

The development of the process of building high-rise buildings was directly related to technical developments in this area. The first serious breakthrough was made in 1854, when the engineer Elisha Graves Otis patented his invention - a passenger elevator. The elevator first entered service in New York in 1857. Since then, houses have been built into the practice of construction, which exceed the level of five floors.

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However, the construction equipment itself was late in development. The first generation of skyscrapers was quite ordinary buildings, just above the built-up ones. Architects of the time adapted the existing construction equipment for the construction of additional floors, while the walls of the lower ones substantially thickened. Thus, the buildings of the old model took all the additional load on the external bearing walls.

But in 1899 appeared Park Row Building, built on the basis of metal fittings: steel structures had a skeleton-base, which took the main load on the core of the building. The outer, relatively fragile shell was made of lightweight materials - glass and aluminum. It is this technology that allowed architects to build buildings with a height of 400 to 500 m in the future.

The erection of high-rise buildings consists of the implementation of known technological processes for the installation or installation of building structures, but the features of these structures and the high-altitude factor on which the work is done predetermine a number of differences in the technology of production.

Despite a significant amount of work in this area, for example [2-9], little attention has been paid to the mechanization of work in the construction of high-rise buildings.

2 Materials and methods

The structures of high-rise buildings presuppose the predominant use for their erection of technologies for installation, concrete and exterior finishing works. The specifics of interior finishing works, which are also mandatory for the construction of high-rise buildings, allow not considering them in terms of technological differences from conventional construction, since the "height" in their performance is limited by the height of a single storey and is determined by the price index of the class of the building.

Mounting operations, in and of themselves, hardly differ from conventional ones: traditional equipment, devices and techniques based on the installation of structures in the design position with the help of a crane are preserved. The composition of the structures, mounted in the frame of high-rise buildings, includes steel columns and beams, wall panels, formwork elements of columns, walls and ceilings. It is possible to note the increased attention to the operational quality control of installation works, but this is typical of all works in the implementation of high-rise construction.

When building high-rise buildings from monolithic reinforced concrete, the formwork systems used also do not have any special differences, except for systems specially designed for high-rise construction in the form of sliding or vertically-adjustable formwork. In such systems, special attention is paid to work safety at altitude. Technological methods of laying and supporting concrete and structures, in general, remain traditional, - the requirements for monitoring these operations are tightened.

The most obvious differences of high-rise construction from the positions of the used machines, mechanisms and devices appear in the means for transporting goods and ensuring the safety of work at altitude.

According to existing data, the use of traditional tower cranes in the construction of buildings is limited by the height of the cargo lifting by 70-80 m (at a higher altitude, the ratio of the parameters "safety, load capacity, mass, cost" becomes suboptimal). Lifting of cargoes by 130-140 m is provided by additional cranes, the vertical tower of which is unfolded on the constructed structures of the building under construction. When building high-rise buildings up to 130 m in height, complex use of the tower (the stage of erecting to a height of 50-60 m) and cranes (the higher part of the building) is often used.

At the altitude of the tasks of 130m or more, the optimum ratio of the parameters "load capacity, mass, cost" of the cranes is exhausted, although individual cranes of this type can provide cargo lifting up to 150m in height. Here begins the field of application of selflifting cranes, which have no restrictions on the height of the lifting of goods. Cranes of this kind are fixed on hard stems of hardness kernels or on the outer contour of the building and have the height of the tower and the structure of fastenings and displacements that ensure their work in layers of 30-40 m height. After the assembly of the building, such cranes are dismantled and, in parts, are lowered by means of winches. In foreign construction practice, a practice is practiced when cranes of this kind are preserved and remain on the roof of the building for later use during major repairs.

For transportation of a concrete mix on height, basically, tubs and concrete pumps of stationary type are used. The use of tubers is determined by the small volumes of monolithic work in the prefabricated frame. For buildings with a monolithic frame, the use of concrete pumps with a capacity of 20-40 m3 / h is more typical. At the same time, most concrete pumps of this type ensure efficient pumping of the mixture by 40-50m vertically, therefore, the mixture is fed to a higher altitude by a cascade, using several pumps and intermediate tanks. Laying of the concrete mixture directly into the formwork is carried out using concrete-spreading arrows mounted on self-elevating or vertically movable mast supports 30-40m high. Strokes of vertical displacement of such devices correspond to the rates of construction of 3-4 floors.

In general, ensuring the supply of concrete mix to the working horizons of high-rise buildings today does not cause problems and is technically well-equipped.

When building high-rise buildings, to the traditional problem of lifting small loads at the stage of finishing works, the problem of mandatory lifting to the height of construction workers at the stage of erection of the frame is added. For these purposes, special cargo-and-passenger lifts are used that have a carrying capacity of up to 3 tons and a capacity of up to 15-20 people with an average lifting height of up to 300 m. The installation of lifts is carried out after the erection of 5-10 floors of the aboveground part and they serve both finishing works and lifting people to floors close to the working horizons of erection or concrete works. The number and type of lifts is determined based on the configuration of the building and the requirements for the organization of construction work at the facility.

Relatively independent technical element to ensure high-rise construction is the means to provide for the construction of enclosing structures of external walls or facade decoration. Here, abstractly from the design of fences, it is required to dynamically provide working platforms for placing people and equipment on the outer contour of the building at high altitude. In the construction of civil buildings for these purposes, forests and hinged scaffolds of various types are traditionally used. However, most types of rack scaffolds are applicable up to 100 m in height. Traditional hinged scaffoldings of small area and carrying capacity also poorly provide the dynamics of work on the facade, requiring significant costs for frequent rearrangements. Solving these problems when carrying out work on the facade of high-rise buildings should be expected with the use of special facade platforms.

The specificity of the erection of high-rise buildings predetermines the use of additional technical means to ensure the safety and acceptable climatic conditions of external construction work. These include wind barriers and protective shelters.

The factor of the presence of a constant wind load at height renders serious attention to the safety of installation work. The conducted researches testify, that at heights of 50 m and more on the lateral surfaces of the building under construction local, randomly directed, vertical wind currents arise.

In addition, in the level of the upper edge of the building, along with the increase in wind load with height, when installing elements of large area (wall panels, formwork panels), horizontal local wind currents of great force arise, significantly complicating the installation. Of course, these wind loads have a purely physiological negative impact on workers. The problem of wind loads is aggravated in the Russian conditions by low air temperatures during the winter period of work. Due to this, the specificity of external works on the construction of high-rise buildings requires the use of wind barriers for installation and exterior decoration, the installation of hothouses and other heated spaces.

In the practice of foreign construction of high-rise buildings, special vertical wind barriers are used throughout the working horizon of the building assembly. Thus, for example, PERI produces similar fences, unifying them with their formwork systems. However, the review of the offers of the market of construction equipment and equipment in the Moscow region does not reveal the presence and systematic use of such devices.

The practice of erecting high-rise buildings of the Moscow-CITY complex has shown that a number of firms use the device of hothouses in the assembly areas of the building frame for a comprehensive solution of wind protection and low temperature issues. At the same time, the choice of windproof and heat-insulating materials, the development of power structures for a heating plant, the choice of air heating equipment, are wholly within the competence of the organization - the general contractor.

The production of facade works in the construction of high-rise buildings is universally performed using windproof and heat-insulating fences (special mesh, fabric curtains, etc.). As a matter of fact, in the zone of work on the facade, a warm-hearth is formed, structurally combined with means of padding. The displacement of such a heat is adequate to the movements of the devices used, the work of assembly and disassembly coincide with the moments of assembly and disassembly of such devices. The constructive solution of this kind of fireplaces and fences is diverse and lies in the competence of the organization that produces the work.

3 Results

High-rise buildings are universally created with a developed buried underground part designed to ensure the perception of vertical and tipping loads from the tower of the building. The area of the underground part, as a rule, exceeds the area of the above-ground part of the building by 1.5-2 times, and the depth of foundations - 10, ... 20m.

A sharp increase in the depth of foundations laid in comparison with the traditional 3-4 m has led to the inability to carry out the development of soil pits of high-rise buildings with the use of natural slopes of excavations, increasing the footprint of the building by 2-3 times. To solve this problem, technologies for the installation of the underground part "wall in the ground" and the methods of sheet pile and pile fencing were in great demand. It should be noted that these technologies require special equipment and equipment, which, organizationally, led to their concentration in the structure of specialized construction organizations that are not in the category of general contractor.

Technological problems of the construction of buried excavations with vertical slope guarding are concentrated around securing a reliable unfolding of walls and soil as a whole, until the creation of a spatially rigid structure of the underground part. In order to solve it, vertical fencing of slopes is often combined with the outer walls of the underground part of the building, using various methods of fencing fastenings and closed methods of soil development with low-dimensional construction equipment along with the construction of piles-columns during the course of soil development. These issues are acute in the construction of high-rise buildings in the zone of existing buildings. Design, approval and approval, direct execution of vertical slope fixing structures, usually refers to the functions of the general contractor.

Earthwork in the installation of the underground part is most often performed using single-bucket excavators equipped with buckets of the direct or reverse shovel type. In this case, the development is carried out by layers of 3-4 m and this kind of work requires a detailed study of the schemes of the movement of excavators and transport. With the use of techniques of closed soil development, forklifts and mini excavators are used; The excavation of soil from the excavation can be carried out with the help of cranes. Earthwork, as a rule, is carried out by specialized construction organizations that have appropriate earth-moving equipment.

The stage of excavation in the construction of high-rise buildings is additionally accompanied by special works connected with water depletion and protection from groundwater. The technology for performing these works requires special equipment and rigging, which also entails the involvement of specialized construction organizations.

The whole complex of works related to the construction of a pit of a high-rise building is much more complicated, long-lasting and expensive compared to similar works on traditional civil buildings. The methods used, the methods and methods of carrying out the work require careful design individual elaboration and a lot of coordination, which predetermines the existence of a special Project for the production of excavation works, including the development of vertical slope design issues, terraced development of the soil together with transport interchanges, solutions for dewatering and protection from groundwater.

The foundation of the foundation slab in the stream of works on the installation of the surface part of the high-rise building is a complex and sufficiently long independent stage requiring special organizational and technological preparation from the general contractor. Very often the construction of the base of high-rise buildings is solved in the form of pile-plate foundations, which precedes the construction of foundation slabs by the work on the construction of ramming piles.

Fundamental slabs of high-rise buildings are universally executed from monolithic reinforced concrete and have rather complicated outlines in terms of thickness 2-4m and a total volume of 3000-4000m3. The practice of domestic construction allows us today to identify the following main technological problems associated with their design:

1. The reinforcing cage of foundation slabs is a powerful lower and upper multilayer mesh, resting on the rods of vertical reinforcement with a system step of 0.5-1 m, with local additional reinforcement in the area of bearing columns and pylons. Because of this, the reinforcing cage becomes an independent structure, requiring solutions to ensure stability and security at all stages of its creation.

2. The foreseen high-strength concretes (usually of class B40 and higher with reduced cement content and increased mobility of the concrete mix) significantly increase the requirements for the processes of manufacturing, transporting and laying the mixture.

3. Requirements for the continuity of the concreting of the foundation slab in combination with the large thickness of the slab and the area of concreting areas lead to:

- to the necessity of slowing down the setting time of the mixture after laying up to 12-20 hours;

- to the use of concrete batching complexes of high productivity in combination with the attraction of a large number of transport equipment;

- to attract a significant number of vibrators and carefully ensure the vibrating of the mixture in all local volumes of installation.

4. The maintenance of massive foundation slabs after laying the mixture proceeds in compliance with extremely stringent temperature requirements for the rates of heating-cooling of concrete and temperature differences between the central and marginal zones. So, for example, with the device of a 4.5m foundation plate of one of the buildings of the Moscow-CITY complex, the design requirements required to limit the absolute temperatures of concrete in the slab of 50oC with a gradient temperature drop over the slab thickness of no more than 2oC. Real provision of these requirements entails the use of hothouses, special methods and means of leveling heating in combination with measures of careful independent temperature control of concrete maintenance in both summer and winter conditions.

The list of technological problems associated with the installation of foundation slabs of the underground part of high-rise buildings could be continued, but the above is sufficient to enable the section on the construction of a high-rise building to have independent and mandatory significance in the Project for the construction of a high-rise building.

4 Discussion

The construction of walls and ceilings of the underground part of the building from monolithic reinforced concrete does not have any significant technological differences in the manufacture of formwork, reinforcement and concrete work. They are characterized, mainly, by increased massiveness (columns, pylons, load-bearing walls, beams), intensive reinforcement and the use of high-strength concretes. Compared with foundation slabs, their installation significantly reduces the intensity of concreting and the technology of concrete work fits perfectly into traditional schemes for the use of automobile or stationary concrete pumps with spreading arrows or is solved using the "crane-bucket" method. Accordingly, there is no problem with the use of cranes of any type to provide shuttering and reinforcement work. Some technological features of their manufacture can be caused by the device of protective coatings in the structure of these structures (waterproofing, insulation, etc.).

The erection of the above-ground part is built using known technologies and technical means. During this period, the construction site is relatively constant continuous construction flow (people, equipment, materials, documents).

Vertical enclosing structures (exterior walls of the building) are arranged either in the cycle of erection of floors (installation of wall panels) or in the form of an independent set of works lagging behind the work on the construction of load-bearing structures of the building. In the latter case, such work is carried out by tiers with a backlog from the construction of structures of 5 or more floors. At this stage of the work, special attention is paid to the safety of work: fences-peaks are installed in the areas of installation works, protective decks are erected over and under the zones of facade works. The rules and techniques for performing such work are specially stipulated in the technological documentation.

Finishing works in the construction of high-rise buildings are performed in a lively manner, as they are erected. The "tiered" finish is directly related to the availability of technical floors in the building, as the floors and interim roofs are being dealt with on these floors and temporary provision of water, heat and energy finishing areas is provided. In view of the combination of different types of work and a large number of workers, this stage of work is also characterized by increased security requirements.

For structures of the underground part of the building, as well as all other monolithic load-bearing reinforced concrete structures of any buildings, careful quality control of the materials used and the resulting structural material is provided. Building norms do not establish any differences for high-rise and other buildings, but in practice, much attention to the construction of high-rise buildings by investors, designers and government supervisors leads to scrupulous compliance with existing provisions, sometimes with reinsurance and unjustified overstatement of requirements. So, for example, the requirements of the structural part of the project to the temperature characteristics of maintaining massive structures in combination with the use of high-strength concretes are seen to be poorly met. Here designers clearly disclaim responsibility for potentially possible (and sometimes simply unavoidable!) Cracks on builders who simply can not technically provide the specified temperature characteristics for maintaining concrete structures on the basis of price levels agreed upon. In addition, it should be noted the existence of a certain arbitrariness of monitoring organizations in assessing the adequacy of technological documentation of facilities due to fuzzy positioning of high-rise buildings in the normative and legal literature on construction.

Recently, there have been major changes in the development and technology of building high-rise buildings, and a significant part of them is connected with the possibility of using digital models. For the successful interaction of all project participants, the so-called BIM-model (The Building Information Model) is used. This system allows you to design a building and make the necessary changes, and can also be used to manage the object after the completion of construction. It allows you to optimize the decision-making system at all stages of work on the object - from idea to implementation. In BIM, a three-dimensional model of the building is created, which all participants of the project can learn on-line (and make their suggestions and changes) on-line. Thus, all changes are instantly announced to all specialists involved in the project, excluding the point of inconsistency of separate sections. In the current situation, when there are a lot of different perspectives, financial and professional interests that affect the result of construction, one of the greatest hopes is the open exchange of information and work together, an easily accessible database created at the very beginning of the project launch. Such a system is largely correlated with the BIM model [10-15].

The possibility of automation of assembly works can be ensured by:

- availability of equipment that receives radio navigation signals from satellites (geodetic receivers in GPS / GLONASS systems) and allows using so-called base station to obtain coordinates and heights with rms errors from 5 mm to 20 mm;
- preliminary creation of a "virtual" information model of the future building (BIM-model);
- preliminary "marking" of assemblies of the mounted structure, which allows "to specify" the exact design position of each element on the BIM-model.

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